THE LIGHTEST NEUTRAL AND DOUBLY CHARGED HIGGS BOSONS OF SUPERSYMMETRIC LEFT-RIGHT MODELS [a]

K. HUITU[1], P.N. PANDITA[1,2], K. PUOLAMÄKI[1]

[1] *Helsinki Institute of Physics, P.O.B. 9, FIN-00014 University of Helsinki, Finland*

[2] *Department of Physics, North Eastern Hill University, Shillong 793022, India*

We review the phenomenology of light Higgs scalars in supersymmetric left-right models. We consider models with minimal particle content (with and without non-renormalizable higher-dimensional terms) and with additional Higgs superfields. The upper bound on the lightest CP-even neutral Higgs boson in these models is larger than in the minimal supersymmetric standard model, and the Higgs couplings to fermions approach those of the Standard Model. Possibly light doubly charged Higgs boson may provide the best signature of these models.

1 The models

The left-right models are interesting for many reasons, e.g. they provide a natural way to generate light masses for the neutrinos via the see-saw mechanism [1]. An important motivation for the supersymmetric left-right models [2−14] is due to the fact [15,16] that if the gauge symmetry is extended to $SU(2)_L \times U(1)_{I_{3R}} \times U(1)_{B-L}$, or to $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, then R-parity is conserved in the Lagrangian of the theory. Thus one of the major problematic features of the MSSM is resolved by a gauge symmetry. Here we will concentrate on the model with the $SU(2)_R$ symmetry, the supersymmetric left-right model (SLRM).

While the problem of R-parity is solved, the particle content of the model is enlarged. In addition to the new superfields containing the gauge bosons of the $SU(2)_R$ symmetry, one has a right-handed neutrino superfield (ν_L^c). The Higgs sector in the SLRM is chosen to have triplets in the spectrum, in which case one can have the conventional see-saw mechanism for neutrino mass generation. The $SU(2)_L$ will be broken mainly by bidoublets which contain the doublets of the MSSM. Thus, the Higgs sector consists of the following superfields:

$$\Phi = \begin{pmatrix} \Phi_1^0 & \Phi_1^+ \\ \Phi_2^- & \Phi_2^0 \end{pmatrix}, \; \chi = \begin{pmatrix} \chi_1^0 & \chi_1^+ \\ \chi_2^- & \chi_2^0 \end{pmatrix} \sim (1,2,2,0),$$

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$$\Delta_R \sim (1,1,3,-2),\ \delta_R \sim (1,1,3,2),\ \Delta_L \sim (1,3,1,-2),\ \delta_L \sim (1,3,1,2). \quad (1)$$

The $SU(2)_L$ triplets Δ_L and δ_L make the Lagrangian fully symmetric under $L \leftrightarrow R$. Left triplets are not needed for symmetry breaking or the see-saw mechanism.

The VEVs preserving the $U(1)_{\rm em}$ gauge invariance can be written as

$$\begin{aligned} &\langle\Phi\rangle = \begin{pmatrix} \kappa_1 & 0 \\ 0 & e^{i\phi_1}\kappa_1' \end{pmatrix},\ \langle\chi\rangle = \begin{pmatrix} e^{i\phi_2}\kappa_2' & 0 \\ 0 & \kappa_2 \end{pmatrix},\ \langle\tilde{\nu}_L\rangle = \sigma_L,\ \langle\tilde{\nu}_L^c\rangle = \sigma_R, \\ &\langle\Delta_R^0\rangle = v_{\Delta_R},\ \langle\delta_R^0\rangle = v_{\delta_R},\ \langle\Delta_L^0\rangle = v_{\Delta_L},\ \langle\delta_L^0\rangle = v_{\delta_L}, \end{aligned} \quad (2)$$

The triplet VEVs v_{Δ_R,δ_R} are, according to the lower bounds [17] on heavy W- and Z-boson masses, in the range $v_{\Delta_R,\delta_R} \gtrsim 1$ TeV. The VEVs $\kappa_{1,2}'$ contribute to the mixing of the charged gauge bosons and to the flavour changing neutral currents, and are usually assumed to vanish. The left-triplet VEVs v_{Δ_L,δ_L} must be small, since the electroweak ρ parameter is close to unity, $\rho = 0.9998 \pm 0.0008$ [17]. With the minimal field content and renormalizable model, the only way to preserve the $U(1)_{em}$ gauge symmetry is to break the R-parity by a sneutrino VEV [4,7].

An alternative to the minimal left-right supersymmetric model involves additional triplet fields, $\Omega_L(1,3,1,0)$ and $\Omega_R(1,1,3,0)$ [9]. In these extended models the gauge group $SU(2)_R \times U(1)_{B-L}$ is broken first to an intermediate symmetry group $U(1)_R \times U(1)_{B-L}$, and at the second stage to $U(1)_Y$ at a lower scale. In this theory the parity-breaking minimum respects the electromagnetic gauge invariance without a sneutrino VEV.

A second option is to add non-renormalizable terms to the Lagrangian of the minimal model [16,11,10]. It has been shown that the addition of terms suppressed by a high scale such as Planck mass, $M \sim 10^{19}$ GeV, with the minimal field content ensures the correct pattern of symmetry breaking in the SLRM with the intermediate scale $M_R \gtrsim 10^{10} - 10^{11}$ GeV, and R-parity remains exact.

2 The upper limit on the lightest CP-even Higgs

In the case of the SLRM we have many new couplings and also new scales in the model and it is not obvious, what is the upper limit on the lightest CP-even Higgs boson mass. This mass bound is a very important issue, since the experiments are approaching the upper limit of the lightest Higgs boson mass in the MSSM.

A general method to find an upper limit for the lightest Higgs mass was presented in [18]. This method has been applied to the mass of the lightest

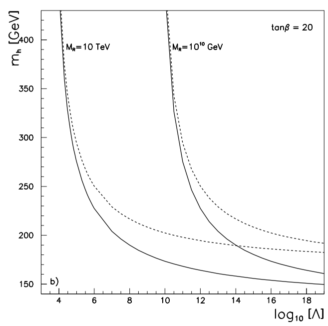

Figure 1: The upper bound on the mass of the lightest neutral Higgs boson. The bi- and trilinear soft supersymmetry breaking parameters are 1 TeV (solid line) and 10 TeV (dashed line).

Higgs, m_h, of SLRM [14] in three cases: (A) R-parity is spontaneously broken (sneutrinos get VEVs), (B) R-parity is conserved because of additional triplets, and (C) R-parity is conserved because of nonrenormalizable terms.

For the minimal model, case (A), the upper bound on m_h is [14]

$$m_h^2 \leq \frac{1}{2v^2}\left[g_L^2(\omega_\kappa^2+\sigma_L^2)^2+g_R^2\omega_\kappa^4+g_{B-L}^2\sigma_L^4+8(h_{\Phi L}\kappa_1'+h_{\chi L}\kappa_2)^2\sigma_L^2+8h_{\Delta_L}^2\sigma_L^4\right], \quad (3)$$

where $v^2=\kappa_1^2+\kappa_1'^2+\kappa_2^2+\kappa_2'^2+\sigma_L^2$ and $\omega_\kappa^2=\kappa_1^2-\kappa_2^2-\kappa_1'^2+\kappa_2'^2$. The addition of extra triplets does not change this bound. Thus, the bound for the case (B), can be obtained from (3) by taking the limit $\sigma_L \to 0$. The total number of nonrenormalizable terms in case (C) is large. However, the contribution to the Higgs mass bound from these terms is found to be [14] typically numerically negligible. Therefore the upper bound for this class of models is essentially the same as in the case (B).

The radiative corrections to the lightest Higgs mass are significant. For the SLRM lightest Higgs they have been calculated in detail [14]. For nearly degenerate stop masses, the radiative corrections on m_h in the SLRM differ in form from the MSSM upper bound only because of new supersymmetric Higgs mixing parameters.

The upper bound on the mass of the lightest Higgs is plotted in Fig.1 as a function of the scale Λ up to which the SLRM remains perturbative. The upper bound is shown for two different values of the $SU(2)_R$ breaking scale, $M_R = 10$ TeV and $M_R = 10^{10}$ GeV, and for two values of soft supersymmetry

breaking mass parameter, $M_s = 1$ TeV and $M_s = 10$ TeV. For large values of Λ the upper bound is below 200 GeV.

2.1 Couplings of the lightest neutral Higgs to fermions in the SLRM

In order to study the phenomenology of the lightest Higgs boson in the SLRM, its couplings to fermions are needed.

In the left-right symmetric models problems with FCNC are expected if several light Higgs bosons exist [19] unless $m_{H_{FCNC}} \gtrsim \mathcal{O}(1\ \mathrm{TeV})$. Thus the relevant limit to discuss is the one in which all the neutral Higgs bosons, except the lightest one, are heavy. It has been shown that in the decoupling limit the Yukawa couplings of the τ's are the same in the SM and the SLRM even if the τ's contain a large fraction of gauginos or higgsinos [14].

3 The lightest doubly charged Higgs

In addition to the lightest neutral CP-even Higgs, it has been known for quite some time [7] that the lightest doubly charged Higgs boson in these models may be light. Whether it is observable in the experiments is an interesting issue, since this particle may both reveal the nature of the gauge group and help to determine the particular supersymmetric left-right model in question.

There are four doubly charged Higgs bosons in the SLRM, of which two are right-handed and two left-handed. The masses of the left-handed triplets are expected to be of the same order as the soft terms. The mass matrix for the right-handed triplets depends on the right-triplet VEV. Nevertheless, it was noticed in [7] that in the SLRM with broken R-parity one right-handed doubly charged scalar tends to be light. Also, in the nonrenormalizable case it is possible to have light doubly charged scalars [12]. On the other hand, in the nonsupersymmetric left-right model all the doubly charged scalars typically have a mass of the order of the right-handed scale [20]. This is also true in the SLRM with enlarged particle content [11]. Thus a light doubly charged Higgs would be a strong indication of a supersymmetric left-right model with minimal particle content.

In Figure 2 a) an example of H^{++} masses with broken R-parity is shown as a function of A_Δ for fixed σ_R. The soft masses and right-handed breaking scale, are of the order of 10 TeV. The maximum triplet Yukawa coupling allowed by positivity of the mass eigenvalues in this case is $h_\Delta \sim 0.4$. Even in the maximal case the mass of the doubly charged scalar $m_{H^{++}} \sim 1$ TeV. In Fig. 2 b) $m_{H^{++}}$ is plotted in the model containing nonrenormalizable terms as a function of the nonrenormalizable b_R-parameter for $v_R^2/M = 10^2$ GeV.

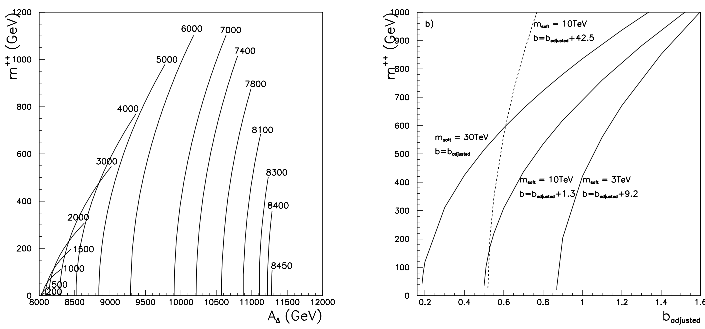

Figure 2: The mass $m_{H^{++}}$ of the lightest doubly charged Higgs. In a) the mass is as a function of the soft trilinear coupling A_Δ. σ_R varies in the allowed range of 100 GeV to 8.45 TeV. In b) the mass is as a function of the nonrenormalizable b_R-parameter. In b) $v_R^2/M = 10^2$ GeV and $D = (3\text{ TeV})^2$ (solid line). For $m_{soft} = 10$ TeV also $D = 10\text{ TeV}^2$ is shown (dashed line). The soft supersymmetry breaking parameters and the b_R parameters are marked in the figure. $\tan\beta = 50$.

3.1 Doubly charged scalars at linear colliders

The collider phenomenology of the doubly charged scalars has been actively studied, since they appear in several extensions of the Standard Model, can be relatively light and have clear signatures. The main decay modes for relatively light doubly charged Higgs are [21] $H^{--} \to l_1^- l_2^-$, where $l_{1,2}$ denote leptons. Thus the experimental signature of the decay is a same sign lepton pair with no missing energy, including lepton number violating final states.

Since the left-right models contain many extra parameters when compared to the MSSM, a great advantage of the pair production is that it is relatively model independent. The doubly charged Higgses can be produced in $f\bar{f} \to \gamma^*, Z^* \to H^{++}H^{--}$ both at lepton and hadron colliders, if kinematically allowed, even if W_R is very heavy, or the triplet Yukawa couplings are very small. The pair production cross section at a linear collider has been given in [22,23]. The cross section remains sufficiently large close to the kinematical limit for the detection to be possible.

Kinematically, production of a single doubly charged scalar would be favoured. This option is more model dependent, but for reasonable parameter range the kinematical reach is approximately doubled compared to the pair production.

4 Conclusions

The lightest CP even Higgs boson in SLRM can be considerably heavier as compared to the lightest Higgs in the MSSM, and its couplings to fermions remain similar to the couplings of the Standard Model Higgs boson. In the SLRM with the minimal particle content one has typically also a light doubly charged Higgs boson. If this particle is found, it is a strong indication of the SLRM with minimal particle content.

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